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Applicant:	Daniel K. Sodickson
Serial No.:	10/771,041
Confirmation No.:	1542
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For:	PARALLEL MAGNETIC RESONANCE IMAGING TECHNIQUES USING RADIOFREQUENCY COIL ARRAYS
Examiner:	Tiffany A. Fetzner
Art Unit:	2859

CERTIFICATE OF MAILING UNDER 37 C.F.R. §1.8(a)

The undersigned hereby certifies that this document is being placed in the United States mail with first-class postage attached, addressed to MAIL STOP AMENDMENT, Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450, on the _______ day of October, 2004.

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MAIL STOP AMENDMENT
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Sir:

DECLARATION UNDER 37 C.F.R. §1.131

I, Daniel K. Sodickson, do hereby declare that:

1. I am the applicant of the above-identified patent application and its priority application, and inventor of the subject matter described and claimed therein.

2. Prior to the date of December 23, 1999, while working in the United States, I conceived the idea of a method and apparatus for implementing parallel MR image reconstruction. Prior to December 23, 1999, I prepared the attached invention disclosure form (Exhibit A), signed and dated in the course of working on the invention; all dates on Exhibit A have been redacted, as I understand is permitted. Additional information not related to the conception, nature or description of the invention has also been redacted.

3. As recorded in Exhibit A, I had by a date prior to December 23, 1999 already reduced to practice the invention set forth in the claims of the above-identified application, which are all drawn to aspects of my invention set forth in the Exhibit A disclosure.

4. Promptly after my preparation of the invention disclosure form described above, it was provided to Beth Israel Deaconess Medical Center's Office of Corporate Research, which acts as my employer's patent coordinator. On information and belief, the disclosure was shortly thereafter sent to our outside patent counsel for the preparation and filing of a patent application.

5. The priority (parent) patent application corresponding to the above-identified patent application no. 10/771,041 was filed on March 14, 2000.

6. On information and belief, work toward the preparation and filing of my parent patent application was substantially continuous from just prior to December 23, 1999 until the filing on March 14, 2000, without significant interruptions and with instructions to file the application at the earliest opportunity.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application, any patent issuing thereon, or any patent to which this verified statement is directed.

Daniel K. Sodickson
Daniel K. Sodickson

10/28/04
Date

CONFIDENTIAL
Office of Corporate Research

Beth Israel Deaconess Medical Center
TECHNOLOGY DISCLOSURE

1. **TITLE OF INVENTION:** (Brief, but comprehensive, technically accurate and descriptive)

A Generalized Basis Approach for Improved Parallel Magnetic Resonance Imaging

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2. **IDENTIFICATION OF CONTRIBUTOR(S):** Please provide the following information for each inventor:

a.	Full name	Daniel K. Sodickson, MD, PhD
b.	Official title or position	Instructor in Medicine, Harvard Medical School Research Scientist, Beth Israel Deaconess Medical Center
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h.	Citizenship	USA

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3. **FINANCIAL SUPPORT/ CONTRACT IDENTIFICATION**. This information is needed to determine whether this invention is subject to any commitments or restrictions arising from the terms of sponsorship.

A. **Identify the specific grant or contract number(s)** (not the account number) and the external sponsors (government agencies, industrial sponsors, private agencies or others) which provided support used to defray costs related to the research from which the invention resulted.

- NIH Grant #R29-HL60802
- Whitaker Foundation Biomedical Engineering Research Grant

B. **Was a biological, chemical or physical material or substance obtained from others to create this invention?**
YES ____ NO __x__
If yes, did a Material Transfer Agreement or other document accompany the transfer?
YES ____ NO _____

EXHIBIT A

4. **Please attach a CONCISE DESCRIPTION OF THE TECHNOLOGY.** Your disclosure should enable someone having knowledge of the field to understand the invention and should cover ALL of the following points:

   a. General purpose and a technical description of what the invention is
   b. Describe the advantages and improvements over the existing technology
   c. Identify commercial applications
   d. Describe what is presently available in the field identifying existing methods, devices or materials (and their shortcomings).
   e. List published material such as patents, commercial literature and scientific articles relating to the invention. Search the internet for patents using:
   www.USPTO.gov (abstracts only)
   www.IBM.com (abstracts and claims)
   pctgazette.wipo.int. (foreign applications which are published 6 months after being filed)

Introduction

Imaging speed is of critical importance in many clinical applications of magnetic resonance imaging. Imaging of the cardiovascular system, for example, must contend with the challenges of cardiac motion, respiratory motion, and blood flow. Improvements in MR image acquisition speed over the past decade have allowed significant advances in the visualization and characterization of moving structures. Nevertheless, physical and physiologic constraints on the switching rate of magnetic field gradients and radiofrequency (RF) pulses place certain basic limits on the speed of traditional MR image acquisitions. Many modern MR scanners already operate close to these limits.

Recently, a new approach to MR image acquisition has been developed, which can extend or circumvent the speed limits traditionally associated with gradient and RF hardware. This approach, known as "Parallel MRI," uses spatial information from arrays of RF coils to perform some portion of the spatial encoding normally accomplished using gradients and RF pulses. The use of multiple effective detectors has been shown to multiply imaging speed, without increasing gradient switching rate or RF power deposition.

This new paradigm of parallel MRI had its practical beginnings with the introduction of the SMASH technique (1-3), which allowed the first accelerated in vivo parallel images to be obtained. Subsequently, several related parallel imaging techniques have been proposed and applied to in vivo imaging. Parallel imaging techniques have tended to fall into one of two general categories, as exemplified by the SMASH (1-3) and the SENSE (4, 5) techniques, respectively. SMASH operates primarily in *k*-space, while SENSE operates primarily in the image domain. Each approach has its particular advantages and limitations.

The work described here represents a generalized formalism in which various techniques such as SMASH and SENSE appear as special cases. The generalized approach allows direct comparison of the two classes of techniques, and provides insight into origins of some of their distinct practical features. Appropriate modification of parameters in the generalized approach also allows the generation of hybrid techniques combining some of the advantages of the *k*-space and the image domain approaches. Furthermore, numerical

conditioning may be incorporated conveniently into the generalized formalism. This important feature of numerical conditioning enables effective compensation for noise or for systematic errors in coil sensitivity calibration, resulting in improved image quality and signal-to-noise ratio under a wide range of conditions. Incorporation of numerical conditioning directly into the parallel image reconstruction using the generalized approach also removes a cumbersome and potentially error-prone sensitivity calibration step involving division of two distinct reference images in the SENSE technique.

In short, the generalized approach described here not only provides a unifying perspective connecting various parallel imaging techniques, but, in combination with appropriate numerical conditioning approaches, it also allows substantive improvements to techniques such as SMASH and SENSE, and enables hybrid approaches with further enhanced performance.

Theory

We begin with the recognition that measured MR signal data is comprised of a generalized series of projections of the underlying distribution of MR-active spins in the imaged volume. A listing of the various projection functions then leads to practical strategies for parallel image reconstruction.

The MR signal detected in any given RF coil is the result of a spatial integration of spin density (ignoring relaxation) against the sensitivity C_l of that coil and against the sinusoidal spatial modulations generated by encoding gradients:

$$S_l(k_x,k_y) = \iint dxdy\,\rho(x,y)\cdot C_l(x,y)\exp(-ik_x x)\exp(-ik_y y) \tag{1}$$

Here, $l = 1,2,\ldots L$ is the index of any component coil in an L-coil array, and $k_x = 0,1,\ldots,N_x-1$ and $k_y = 0,1,\ldots N_y-1$ are the k-space indices representing different frequency- or phase-encoding gradient steps. In other words, the signal comprises integrations or projections of the spin density against $L*Nx*Ny$ distinct functions

$$B_l(x,y,k_x,k_y) = C_l(x,y)\exp(-ik_x x)\exp(-ik_y y) \tag{2}$$

The integral in Eq. (2) can be approximated with a discrete sum as follows, using a single k-space index $k = (k_x,k_y)$ and a corresponding single pixel index $j = (x,y)$:

$$S_l(k_x,k_y) \equiv S_{kl} \approx \sum_j \rho_j \cdot C_{jl}\exp(-2\pi ijk) = \sum_j \rho_j \cdot B_{jkl} \tag{3}$$

For any given coil l, this is just a discrete Fourier transform (DFT), which is easily inverted with an inverse DFT:

$$C_{jl}\rho_j \approx \frac{1}{N}\sum_k S_{kl}\exp(2\pi ijk) \tag{4}$$

Notice, however, that if the signals from all the coils in the array are grouped together into a single index $p = (k,l)$, a matrix equation is obtained for the spin density without modulation by any coil sensitivity:

$$\rho_j \approx \sum_p S_p B_{jp}^{-1} \tag{5}$$

In other words, if B^{-1} can be calculated, the spin density can be determined.

If a complete set of N_y phase encoding gradients are applied, the **B** matrix has dimension (N_x*Ny*L) x (N_x*Ny). This is clearly overdetermined. Phase encoding gradient steps may be omitted up to a maximum factor of L, and **B** will remain invertible in principle. In other words, when spatial information from an array of coils is available, the spin density may be determined from a reduced set of phase encoding gradients. This is the basis of spatial encoding in parallel imaging.

The structure of the **B** matrix is indicated graphically in Figure 1. In general, **B** will have dimension (N_x*Ny*L/M) x (N_x*Ny), where M is the fraction of omitted gradient steps. The example in the figure shows a segment of the **B** matrix at a given x position, with 3 component coils and a set of 8 phase encode gradient steps. Let us say that we wish to generate a reconstructed image with the equivalent of 16 phase encode gradient steps (i.e. we specify that $M = 2$).

The rows of **B** in this example represent 3*8 = 24 vectors in a 16-dimensional space. Inversion operates by converting these vectors to a basis of 16 vectors spanning the space. Particular choices of the target basis result in inversion strategies which may be shown to be equivalent to SMASH or to SENSE. Alternatively, hybrid approaches may be designed by choosing intermediate target bases, or by applying various approximations to the inversion.

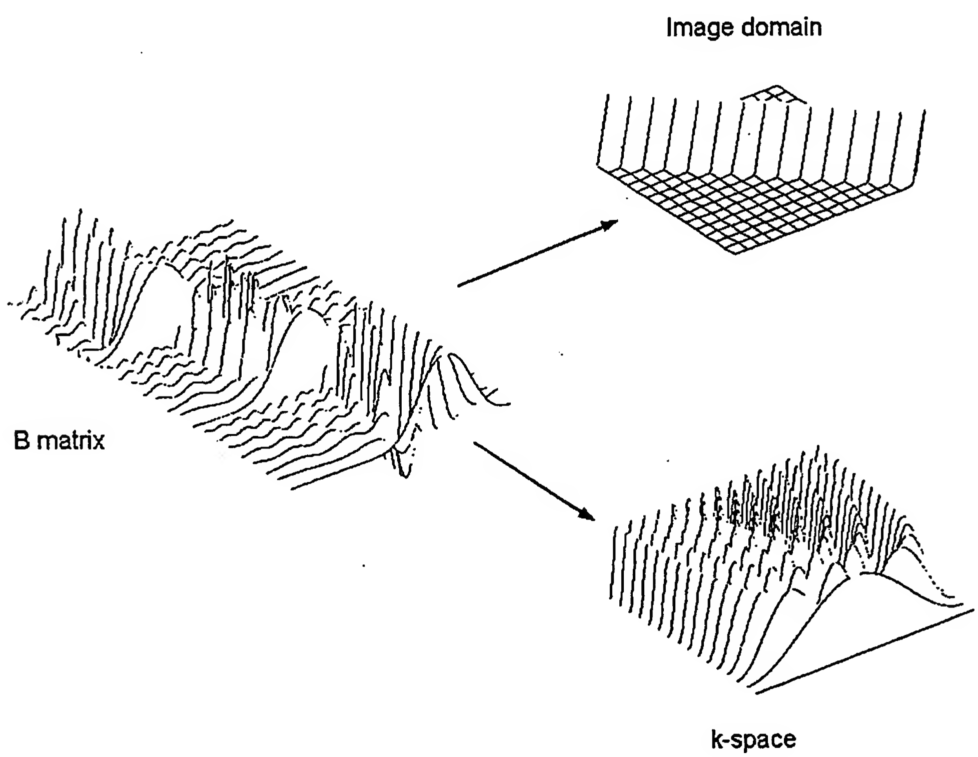

Figure 1: Graphical depiction of a **B** matrix, with different basis transformations leading to k-space or image domain reconstructions, respectively.

Image-domain reconstructions: the pixel basis

Direct inversion of the **B** matrix yields a matrix which when multiplied by **B** produces the identity matrix. From the perspective of basis transformations, this represents transformation to a basis made up of distinct delta functions at each pixel of the image. For particular choices of inversion strategy, this may be shown to reduce to a SENSE image reconstruction, or to a reconstruction using the related subencoding (6) technique.

k-space reconstructions: the Fourier basis

Alternatively, the Fourier transformation may be factored out of the **B** matrix, and the tranformed **B** matrix may be inverted independently from the FT matrix. This procedure corresponds to transformation to a Fourier basis made up orthogonal sinusoidal modulations. One further simplication yields a procedure equivalent to the SMASH image reconstruction.

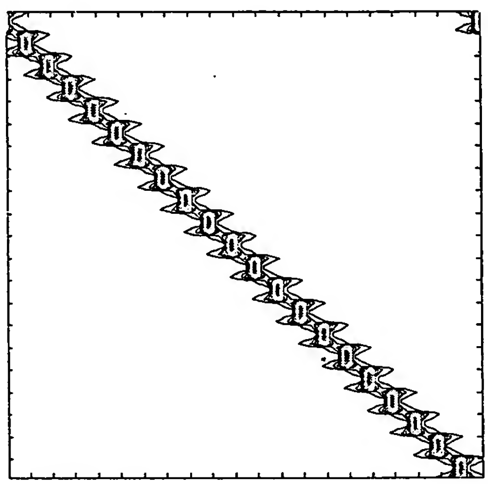

Figure 2: Simulated modulation function matrix **B** for six-fold acceleration (M = 6) with a six-element coil array (L = 6). The Fourier transform has been factored out of **B**, resulting in a nearly block diagonal matrix.

The transformed **B** matrix may be shown to be nearly block diagonal in many cases, as shown in Figure 2. SMASH image reconstruction corresponds to inverting only a subset of the transformed matrix, and assuming that the results apply equally well to all sub-blocks. This assumption, which is based upon emulating the physics of phase encoding gradients, serves both to reduce image reconstruction time and to alleviate potential numerical instabilities which may result from inversion of the larger matrix in the presence of noise or systematic sensitivity calibration errors.

Hybrid reconstructions

One type of hybrid reconstruction results simply from expanding the inverted sub-blocks described above. Such an approach is shown schematically in Figure 3. These hybrid reconstructions share some of the numerical stability and efficiency of the SMASH technique, while also allowing some of the pixel-by-pixel control inherent in the image domain techniques.

Another form of hybrid reconstruction results from using a target basis intermediate between the pixel basis and the Fourier basis described above. For example, a partially localized basis such as a wavelet basis may be used.

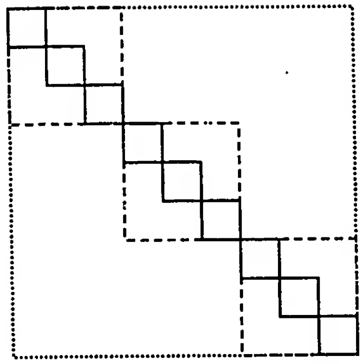

Figure 3: Schematic illustration of hybrid reconstruction approach using inverted sub-blocks of varying size. Solid boxes: minimum sub-block size corresponding to SMASH reconstruction. Dotted box: maximum sub-block size corresponding to inversion of the full B matrix in image domain reconstructions. Dashed boxes: expanded sub-block size corresponding to hybrid reconstruction.

Numerical conditioning

In addition to the numerical conditioning provided by sub-block diagonalization, further numerical conditioning may be added directly to the **B** matrix inversion. In the overdetermined case, when **B** is rectangular with $M < L$, a generalized inverse procedure must be used. One such procedure involves performing a singular value decomposition (SVD) of the **B** matrix

$$\mathbf{B} = \mathbf{U} \cdot \mathbf{S} \cdot \mathbf{V} \tag{6}$$

where **U** and **V** are unitary matrices and **S** is a diagonal matrix containing eigenvalues of **B** in order of decreasing size. The inverse may then be performed as

$$\mathbf{B}^{-1} = \mathbf{V}^{\dagger} \cdot \mathbf{S}^{-1} \cdot \mathbf{U}^{\dagger} \tag{7}$$

The smallest eigenvalues in **S** represent potential numerical instabilities in the reconstruction. Since small eigenvalues will be inverted to large values in the inverse $\mathbf{S}^{-1}$, either noise or systematic errors in sensitivity calibration affecting the eigenvectors associated with these small eigenvalues will be amplified in the reconstruction. Such amplification may be prevented by establishing a minimum eigenvalue threshold and performing one of the following procedures:

1) Eliminate all eigenvalues below the eigenvalue threshold from the inversion.
2) Set all sub-threshold eigenvalues equal to the threshold value.
3) Add the threshold value to all eigenvalues.

The result of this process is to modify or eliminate from the inversion the components most responsible for noise and error propagation, resulting in improved signal to noise ratio and reduced artifact in the reconstructed images.

The price of these improvements is the omission of certain features of the reconstructed image in regions most susceptible to numerical instability. Unlike the sensitivity threshholding procedure described in (4, 5), which eliminates all regions falling below an established intensity and/or density threshold, the SVD approach results in an automatic threshholding strategy which only excludes or approximates regions of the image which are destined to yield large errors in the reconstruction. As a result, it may be used in conjunction with simple *in vivo* sensitivity references, without requiring additional processing or acquisition of an accompanying body coil image.

Eigenvalue conditioning may be applied to B matrix inversions in the image-domain pixel basis, the k-space Fourier basis, or any mixed basis. Furthermore, if an alternative generalized inverse procedure is used, such as the least-squares pseudoinverse

$$\mathbf{B}^{-1}_{\text{pseudo}} = \left(\mathbf{B}^{\dagger}\mathbf{B}\right)^{-1}\mathbf{B}^{\dagger} \tag{8}$$

eigenvalue conditioning may still be applied through an SVD of the inverse $\left(\mathbf{B}^{\dagger}\mathbf{B}\right)^{-1}$.

Results

Figure 4 shows several examples of generalized basis parallel image reconstructions in a phantom imaging experiment.

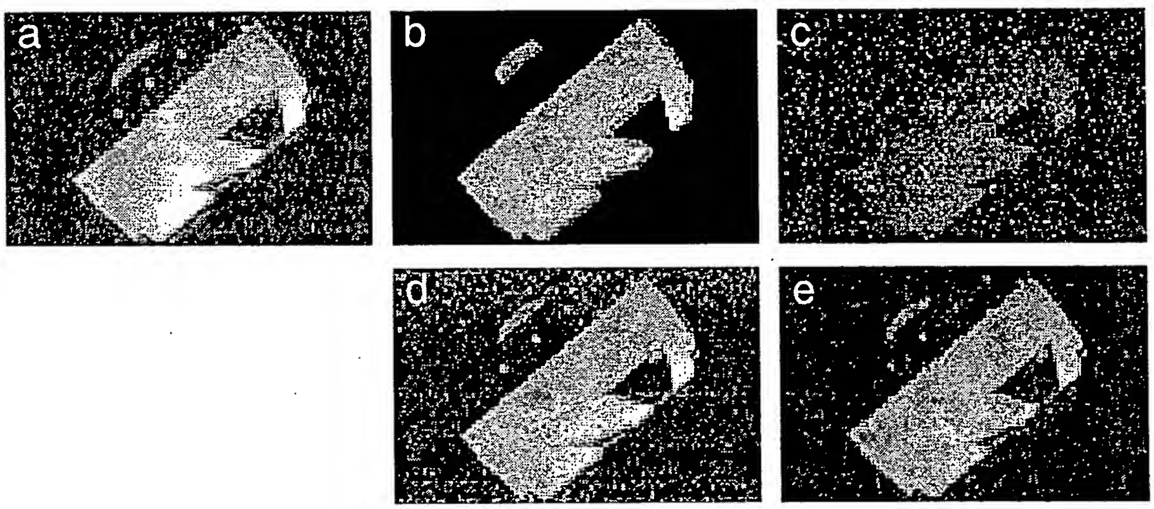

Figure 4: a) Reference image. b)-e) Six-fold accelerated phantom images in a double-oblique image plane. b) SENSE reconstruction, processed sensitivity reference (surface coil and body coil). c) Subencoding reconstruction, raw surface coil sensitivity reference. d) Generalized basis reconstruction with SVD eigenvalue threshold, raw surface coil reference. e) Generalized basis extended sub-block hybrid reconstruction, raw surface coil reference.

Practical issues

The dimensions of the **B** matrix may become quite large when images of high spatial resolution and large matrix size are acquired, and the inversions may consequently become both memory-intensive and time-consuming. Since the x and y integrals in Eq. (1) above are interchangeable, however, a separate smaller inversion may be performed for each position in the non-coil-encoded direction, and parallel image reconstruction may proceed line by line. This can represent a significant savings in image reconstruction time.

Areas of potential claims

Method and apparatus to implement generalized basis transformations for parallel MR image reconstruction, which may be made to converge to SMASH or SENSE/subencoding, or to hybrid reconstructions which balance the advantages of each to yield higher quality images than would be possible with either alone.

Numerical conditioning methods for the reconstructions described above, to improve noise and error propagation and to allow use of in vivo sensitivity references without thresholding or extensive post-processing.

Tailored image reconstruction hardware and software, which may be combined with tailored RF coil arrays and interfaced with clinical and research MRI systems for improved imaging speed and efficiency.

Additional information

For additional information, please see the attached abstract (p. 10), which has been submitted for an upcoming conference of the International Society for Magnetic Resonance in Medicine in April of 2000.

References

1) Sodickson DK, Manning WJ. Simultaneous acquisition of spatial harmonics (SMASH): fast imaging with radiofrequency coil arrays. Magn Reson Med 1997;38(4):591-603.
2) Sodickson DK, Griswold MA, Jakob PM. SMASH Imaging. Magn Reson Imaging Clin N Am 1999;7(2):1-18.
3) US Patent #5,910,728, June 8 1999, Sodickson DK inventor, BIDMC assignee. Simultaneous Acquisition of Spatial Harmonics (SMASH): Ultra-Fast Imaging with Radiofrequency Coil Arrays.
4) Pruessmann KP, Weiger M, Scheidegger MB, Boesiger P. SENSE: Sensitivity encoding for fast MRI. Magn Reson Med 1999;42(5):952-962.
5) International patent application #PCT/IB99/00652, international publication #WO 99/54746, October 28, 1999. Pruessmann KP, Weiger M, Scheidegger MB, Boesiger P inventors. Philips Electronics assignee.
6) Ra JB, Rim CY. Fast imaging using subencoding data sets from multiple detectors. Magn Reson Med 1993;30(1):142-145.

A Generalized Basis Approach to Spatial Encoding with Coil Arrays: SMASH-SENSE Hybrids and Improved Parallel MRI at High Accelerations

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Introduction

The past few years have seen the emergence of a new paradigm of rapid MR imaging in which multi-component detector arrays are used to perform some fraction of image data acquisition in parallel. Parallel imaging techniques have tended to fall into one of two general categories, as exemplified by the SMASH (1) and the SENSE (2) techniques, respectively. SMASH operates primarily in k-space, while SENSE and the related "subencoding" reconstruction technique (3) operate primarily in the image domain. Each approach has its particular advantages and limitations.

Here a generalized formalism is presented directly demonstrating the precise relationship between SMASH and the image domain reconstructions. Not only does this formalism lend insight into the similarities and differences between the techniques, but it also allows the generation of hybrid reconstructions exploiting the advantages of both. In addition, it facilitates the introduction of numerical conditioning which may be used to improve the quality of parallel image reconstructions, especially at high acceleration factors. In this work, elements of the generalized formalism are described, and its use is demonstrated in imaging experiments.

Theory

Each acquired MR signal data point may be viewed as a spatial integration of the true image against the joint modulation functions imposed by applied gradients and component coil sensitivities:

$$S_l(\mathbf{k}) = \int d^3x \rho(\mathbf{x}) C_l(\mathbf{x}) \exp(-i\mathbf{k}\cdot\mathbf{x}) \equiv \int d^3x \rho(\mathbf{x}) B_l(\mathbf{k},\mathbf{x}) \qquad (1)$$

Here l is the array element number, C_l is the sensitivity of coil l, ρ is the apparent spin density including relaxation effects, and k is the wavenumber of a periodic function resulting from evolution in frequency- and phase-encoding gradients. The general theory of sensitivity encoding outlined in (2) begins with a similar starting point.

If the spatial integral in Eq. (1) is approximated with a discrete sum, we may write the signal S_{lk} as

$$S_{lk} \approx \sum_x B_{lkx} \rho_x \qquad (2)$$

or, in matrix form,

$$\mathbf{S} \approx \mathbf{B} \cdot \boldsymbol{\rho} \qquad (3)$$

The central step in a parallel image reconstruction now involves inverting the matrix **B** to recover the spin density ρ.

In the discrete model of Eq. (3), the various modulation functions present in the rows of **B** may be recognized as vectors in a vector space which also contains the reconstructed image. In particular, for an acceleration factor of M, if (N/M) encoding gradient steps are used with an array of L component coils, and the desired reconstructed image is to be made up of N pixels, **B** comprises a set of $(N/M)*L$ vectors spanning an N-dimensional vector space. In other words, the acquired MR signal simply represents $(N/M)*L$ different projections of the "true" image onto a mixed Fourier and sensitivity basis representing the target image. Various basis transformations may then be performed to facilitate and condition the inversion of **B**.

If **B** is transformed to the Fourier basis, i.e. if the Fourier transform is factored out of the inversion, the relationship between k-space and image domain approaches becomes readily apparent. It may be shown that SMASH represents inversion of a small subset of the larger matrix. This inverted subset is then replicated in a block diagonal manner to form the full inverse. SENSE, on the other hand, involves a particular approach to inversion of the full matrix with elements that have been smoothed, filtered and thresholded using the sensitivity mapping procedure described in (2).

In many cases, the transformed matrix is already nearly block diagonal, so that the SMASH reconstruction represents a compact and computationally efficient solution to the general problem. Figure 1 shows a contour plot of the elements of a simulated **B** matrix for such a situation. In cases for which the matrix does not have this property, the block diagonalization inherent in SMASH reconstruction provides numerical conditioning at the expense of global accuracy. Rather than smoothing coil sensitivities, SMASH may be shown to entail a smoothing of the spatial variations among pixel-by-pixel weighting factors in the reconstruction, which serves to control the localized effects of noise and regional sensitivity calibration errors.

Using the generalized basis approach described above, hybrid techniques may be formed by simply extending the size of the inverted sub-block. This allows a smooth trade-off between the numerical conditioning inherent in the SMASH reconstruction and the pixel-by-pixel control of SENSE and subencoding.

Conditioning may also be introduced explicitly into the reconstruction using additional straightforward basis transformations. For example, a singular value decomposition (SVD) of the **B** matrix yields the eigenfunctions of **B** in order of decreasing eigenvalue. Eigenvalue thresholds may then be applied to exclude from the inversion those components most responsible for noise and error propagation. Unlike the sensitivity threshholding procedure described in (2), which eliminates all regions falling below an established intensity and/or density threshold, the SVD approach results in an automatic threshholding strategy which only excludes or approximates regions of the image which are destined to yield large errors in the reconstruction. As a result, it may be used in conjunction with simple *in vivo* sensitivity references, without requiring additional processing or acquisition of an accompanying body coil image.

Methods and Results

Generalized basis reconstructions were carried out and compared with pure SMASH or pure SENSE or subencoding reconstructions for phantoms and for *in vivo* cardiac images in a healthy adult volunteer. By appropriate tuning of parameters in the generalized approach, images were made pixel-by-pixel identical with either SMASH or SENSE reconstructions. Alternatively, additional conditioning was added through hybrid reconstructions and/or eigenvalue thresholds. Figure 2 shows several double-oblique phantom image reconstructions at a factor of 6 acceleration – the theoretical maximum for the six-element coil array used in these experiments.

Discussion

Numerical conditioning becomes particularly important at high acceleration factors, when the matrix inversions involved in any parallel reconstruction strategy can most easily become singular. It is also important for large angulations of the image plane with respect to the coil array, or in general for any situation in which the spatial distinctness of component coil sensitivities is degraded. The generalized basis approach outlined here allowed improved reconstructions of double-oblique images at a high acceleration factor. It also allowed use of simple *in vivo* sensitivity references, preserving small regions of signal surrounded by noise, such as pulmonary blood vessels in thoracic images. Future work will involve optimization of the generalized basis approach for clinical applications of parallel MRI at high accelerations.

References

1 Sodickson DK, et al., MRM 1997; 38:591-603.
2 Pruessmann KP, et al., MRM 1999; 42:952-962.
3 Ra JB, et al., MRM 1993; 30:142-145.

Figure 1: Simulated modulation function matrix **B** *for six-fold acceleration (M = 6) with a six-element coil array (L = 6).*

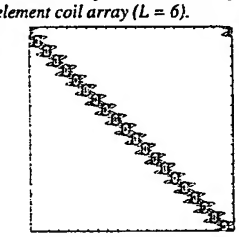
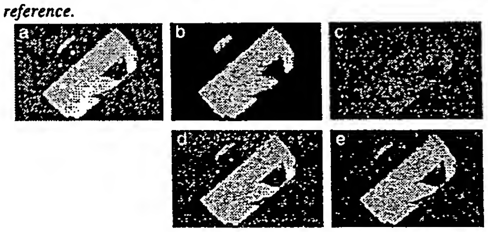


Figure 2: a) Reference image. b)-e) Six-fold accelerated phantom images in a double-oblique image plane. b) SENSE reconstruction, processed sensitivity reference (surface coil and body coil). c) Subencoding reconstruction, raw surface coil sensitivity reference. d) Generalized basis reconstruction with SVD eigenvalue threshold, raw surface coil reference. e) Generalized basis extended sub-block hybrid reconstruction, raw surface coil reference.



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5. **PUBLIC DISCLOSURE / PUBLICATION PLANS**: In the United States, a patent application must be filed no later than one year after public disclosure of the invention in detail. In other countries, filing must take place before public disclosure; however, where there has been a U.S. filing before publication, a one-year grace period is granted for foreign filing. Public disclosure includes abstracts and presentations at scientific meetings (including poster sessions), public seminars, publications, disclosure to others outside of the Medical Center who have not signed a confidentiality agreement, and use, sale or offer of sale of the invention. Identify dates and circumstances of any such disclosures. Also, indicate your future disclosure or publication plans, and NOTIFY the Office of Corporate Research if the invention becomes publicly disclosed or published in the future (whether by plan or inadvertently).

The attached abstract has been submitted to the confidential review board for an international conference on Magnetic Resonance in Medicine to be held on April 1-7 2000. Abstracts for this conference are expected to be made public some time in March.

6. **Please attach an ABSTRACT OF THE INVENTION:** This will be used in our campaign to promote the invention and should, therefore, be no longer than a typewritten page and not contain confidential information.

   Please see the attached submitted conference abstract.

CONFIDENTIAL
Beth Israel Deaconess Medical Center

7. POTENTIAL LICENSEES. Provide as much detail as possible.

a. List any commercial entities that may be interested in licensing this invention.

b. List commercial entities, if any, that you specifically do not want contacted regarding this technology and please indicate why.

1) Large Magnetic Resonance Imaging system manufacturers: Siemens, Philips, General Electric
2) Small MR or radiofrequency coil companies
3) Venture capitalists

I (we) hereby agree to assign all right, title, and interest to this invention to Beth Israel Deaconess Medical Center (Medical Center) and agree to execute all documents as requested, assigning to Medical Center our rights in any patent application filed on this invention, and to cooperate with the Medical Center Office of Corporate Research in the protection of this invention. Medical Center will share royalty income derived from the invention with the inventor(s) according to its standard policies.

DATE: **INVENTOR(S)' SIGNATURE(S):**

Daniel K. Sodickson

Witness: Disclosed to and understood by me on:

DATE: **SIGNATURE:**